Blob Studies in the MAST SOL

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CCFE
CULHAM CENTRE FOR FUSION ENERGY

Outline

- Introduction and Motivation
- 2D Blob/Hole Simulations in BOUT++
- 3D SOL Filament Simulations in BOUT++

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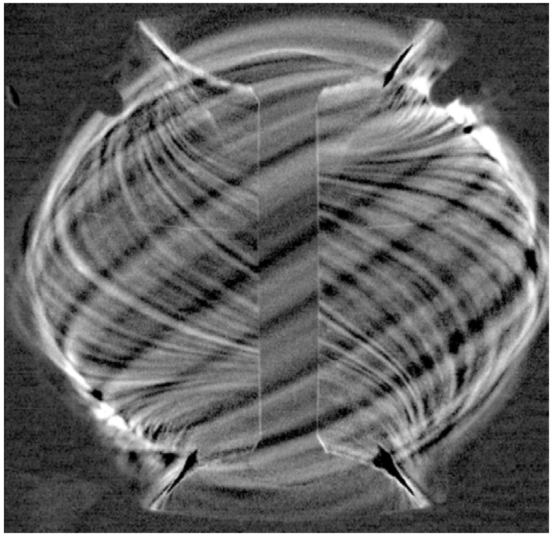
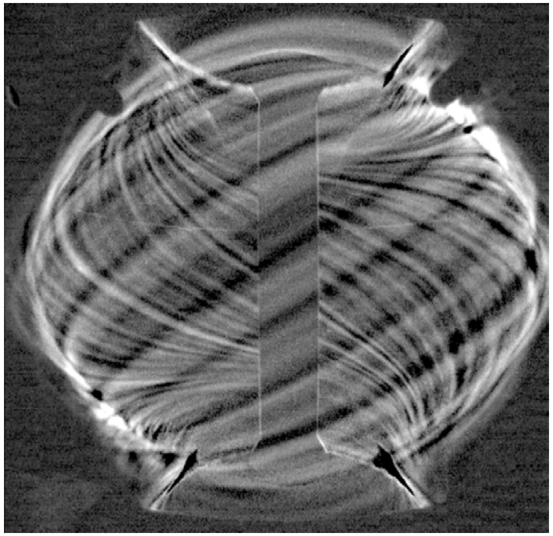
Motivation



B.D.Dudson *et.al,* Plasma Phys. Control. Fusion, **50** (2008) 124012

- Filaments/blobs are synonymous with magnetically confined plasmas
- They provide a strong component of intermittent, non-local transport into the SOL
- They can play a dominant role in determining SOL width, first wall and divertor power loading and impurity transport

Motivation



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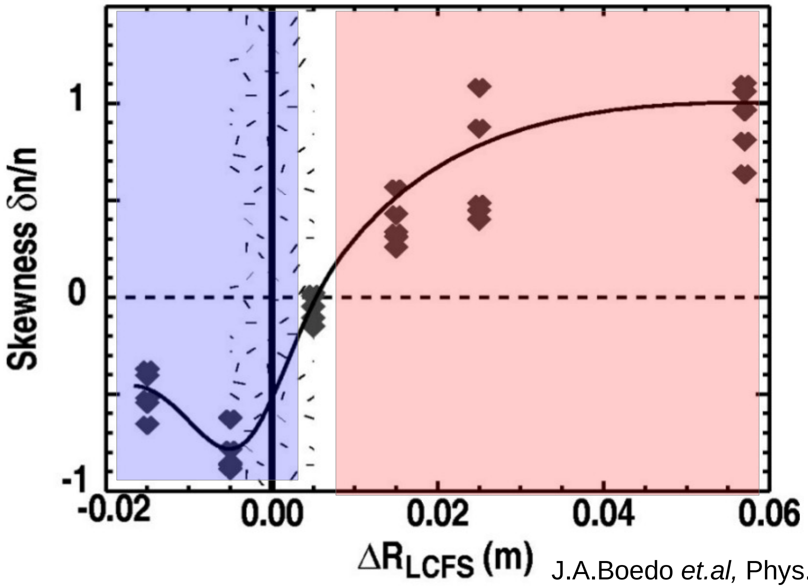
- They provide a strong component of intermittent, non-local transport into the SOL
- They can play a dominant role in determining SOL width, first wall and divertor power loading and impurity transport

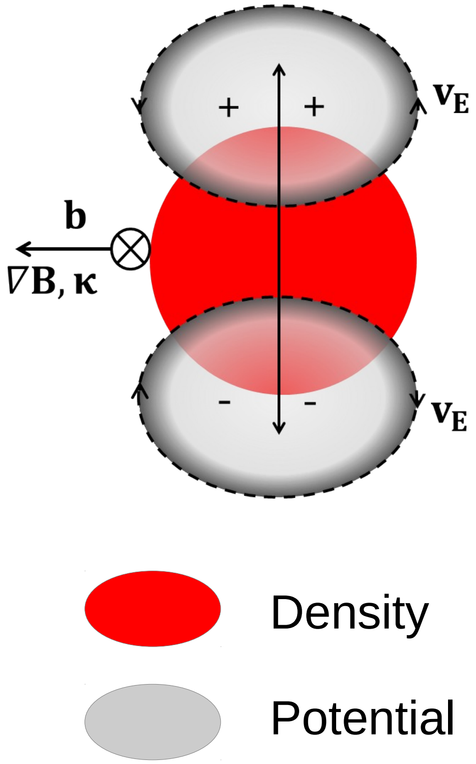
- Skewness of the PDF of density fluctuations is positive in the SOL
    - Blobs
- But negative towards the LCFS
    - Holes



J.A.Boedo *et.al*, Phys. Plasmas, **10** (2003) 1670

Motivation

- Krasheninnikov (Phys.Lett.A, 2001) showed that blobs in a vacuum can propagate ballistically
- Forces perpendicular to the field polarize the blob, leading to the formation of two counter rotating vortices



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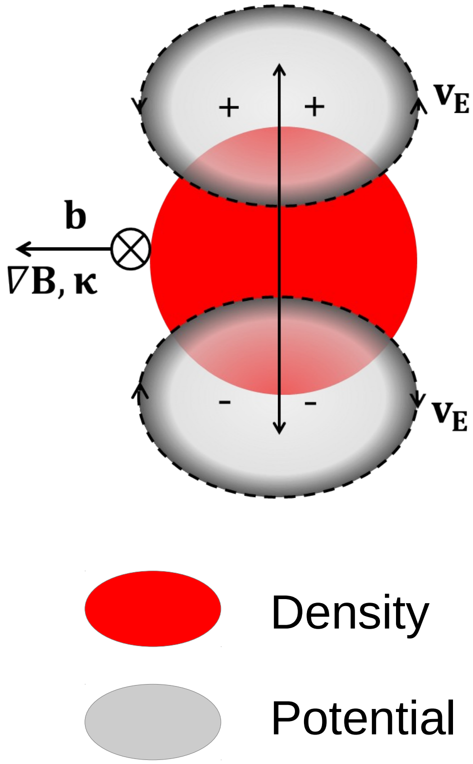
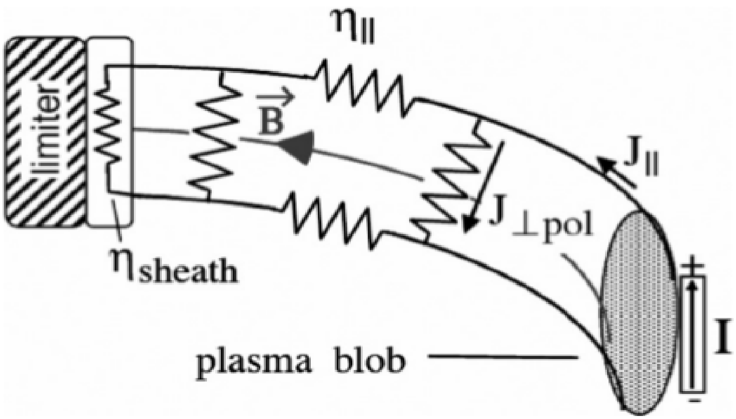


- The blob can be thought of as an equivalent circuit
- Radial velocity is determined by the path of least resistence



D.A.D'Ippolito *et.al,* Phys. Plasmas, 1**8** (2011) 060501

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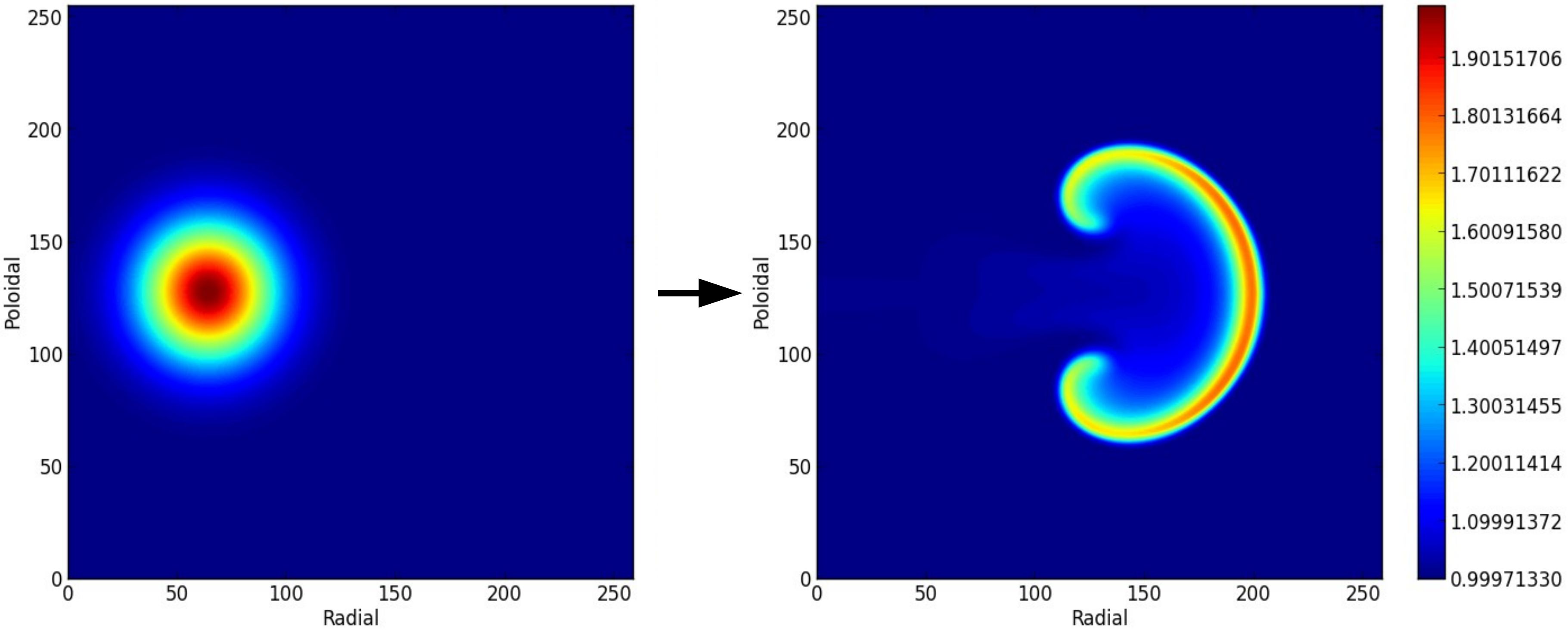
2D Blobs/Holes

- Blobs extensively studied since Krasheninnikov, Phys Lett A, 2001
- Show three main types of motion (see BOUT/examples/blob2D for implementation)

Inertially limited

$$\rho_s^2 \frac{\partial}{\partial t}\nabla_\perp^2\phi = \boxed{\frac{2c_s\rho_s}{nR}\frac{\partial n}{\partial z}} - \boxed{\rho_s^2 \mathbf{v}_E\cdot\nabla\nabla_\perp^2\phi} + \frac{2}{\eta_{sh}L_{||}n}J_{sh}$$



2D Blobs/Holes

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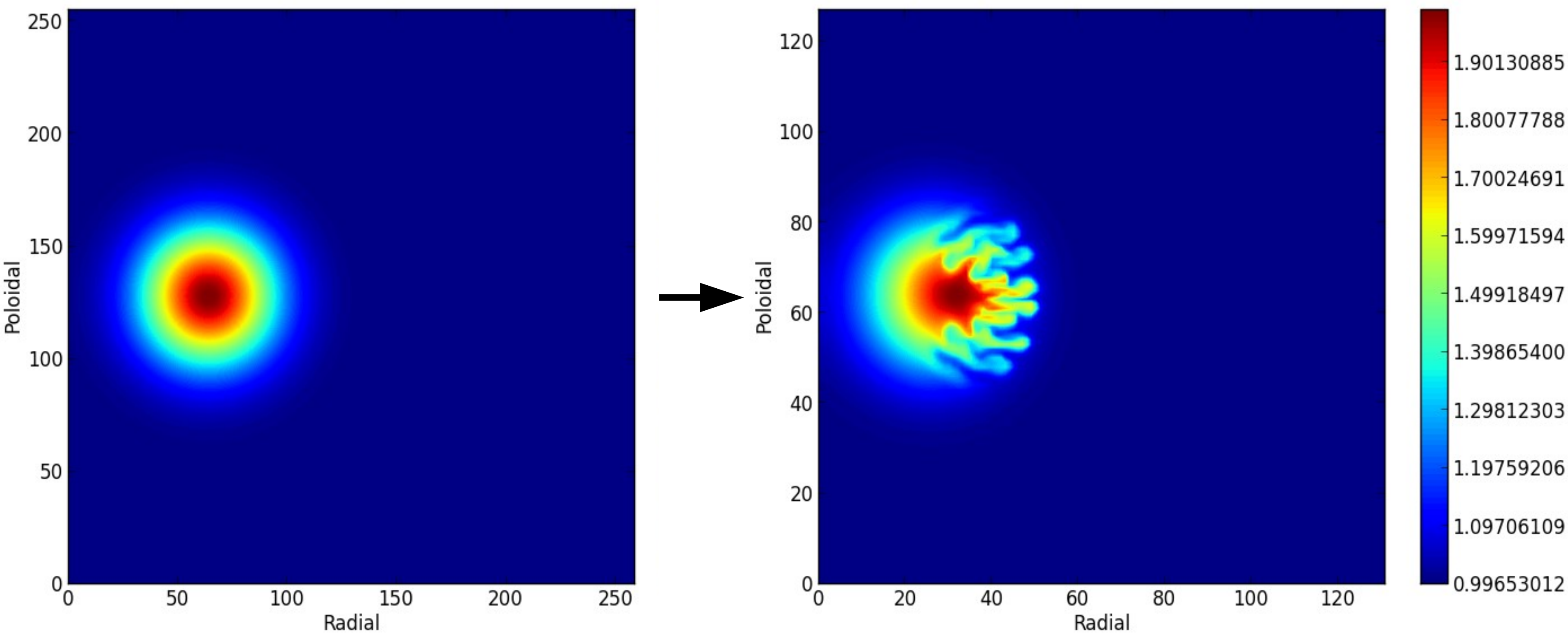
Sheath limited

$$\rho_s^2 \frac{\partial}{\partial t} \nabla_\perp^2 \phi = \boxed{\frac{2 c_s \rho_s}{nR} \frac{\partial n}{\partial z}} - \rho_s^2 \mathbf{v}_E \cdot \nabla \nabla_\perp^2 \phi + \boxed{\frac{2}{\eta_{sh} L_{||} n} J_{sh}}$$



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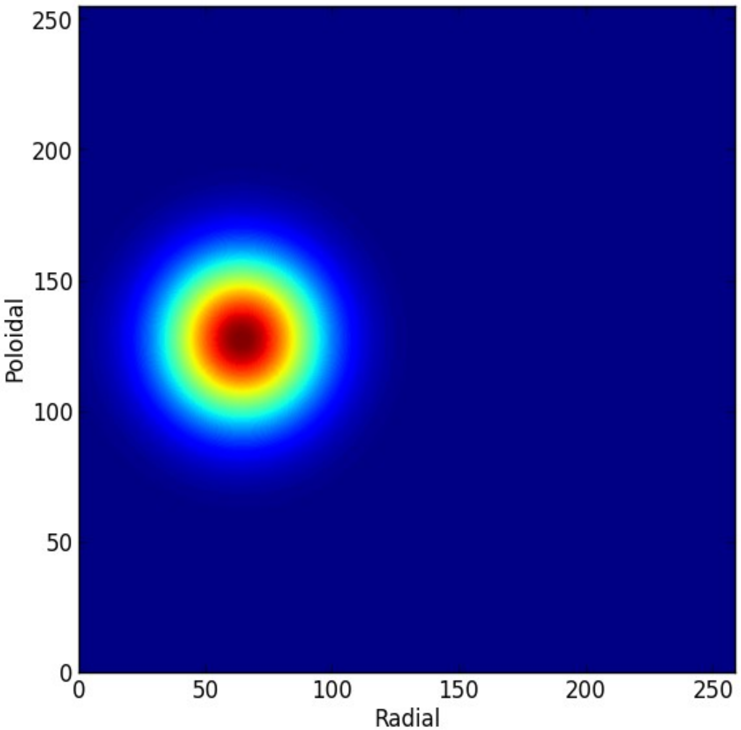
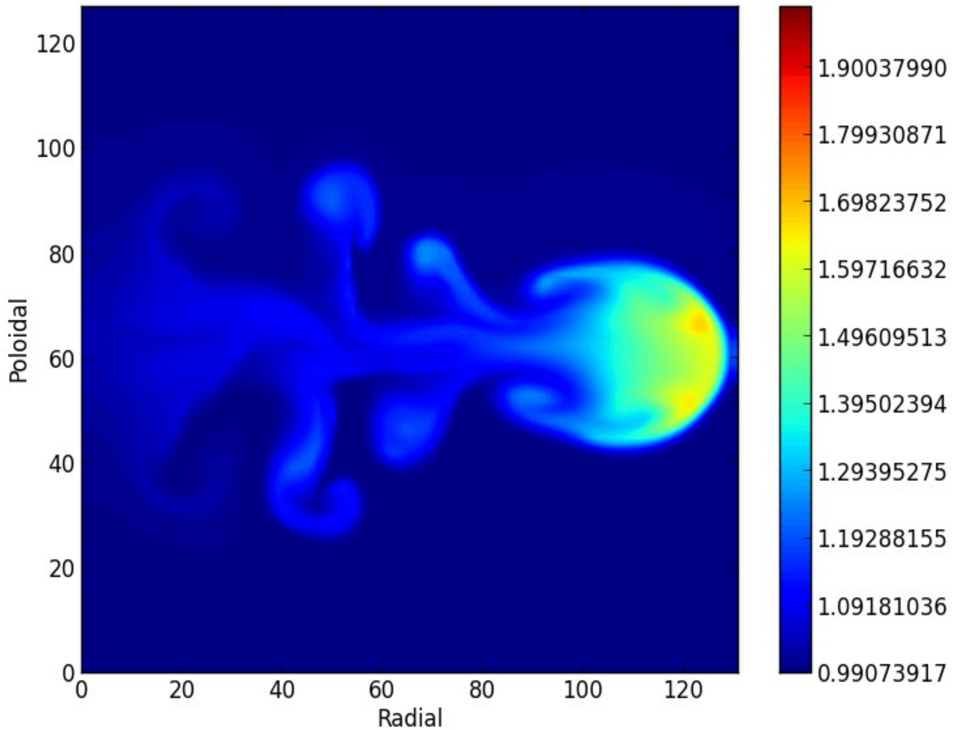
Coherent Motion

$$\rho_s^2 \frac{\partial}{\partial t} \nabla_\perp^2 \phi = \boxed{\frac{2 c_s \rho_s}{nR} \frac{\partial n}{\partial z}} - \boxed{\rho_s^2 \mathbf{v}_E \cdot \nabla \nabla_\perp^2 \phi} + \boxed{\frac{2}{\eta_{sh} L_{||} n} J_{sh}}$$





2D Blobs/Holes

- Holes are proposed as a method of impurity transport in the edge
  - Are the dynamics of holes the same as blobs?
- Blobs can propagate in vacuum but holes are ***defined*** by a background density

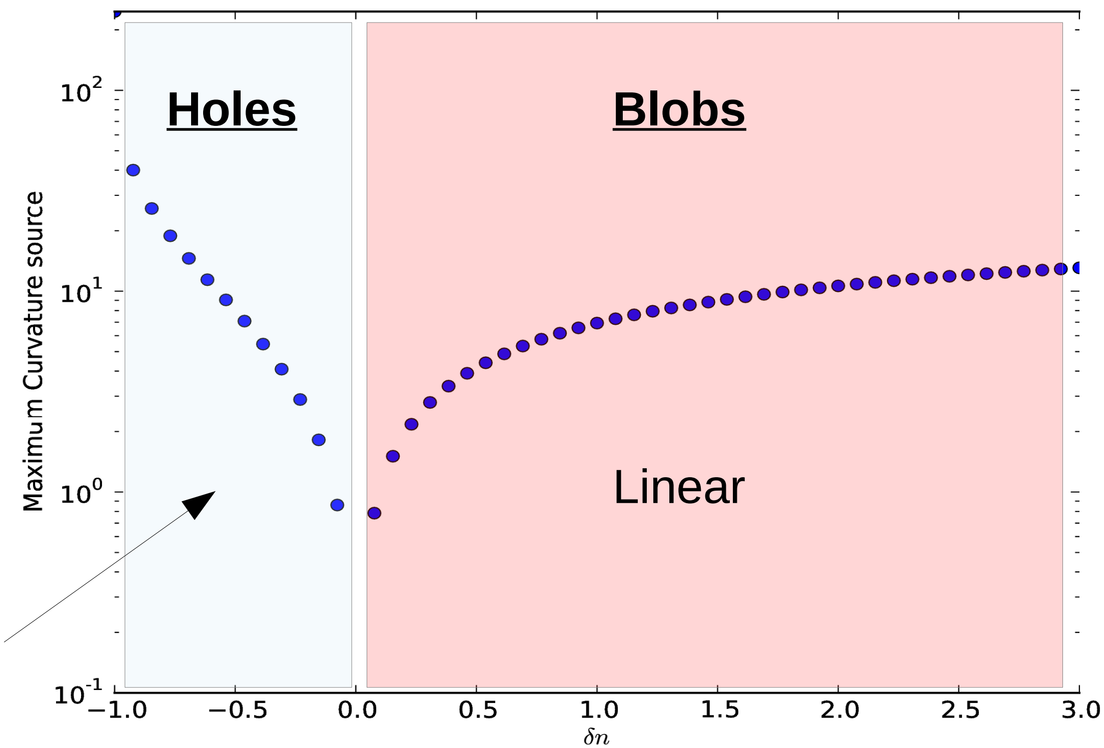
$$n = n_0 \left(1 + \delta n \exp\left[-\left(\frac{x^2}{\delta_x^2} + \frac{z^2}{\delta_z^2}\right)\right]\right)$$

- This gives the Initial current source in the blob circuit for blobs **or** holes

$$\frac{2c_s\rho_s}{R}\frac{\partial \ln(n)}{\partial z} = \frac{2c_s\rho_s}{R}\frac{2z}{\delta_z^2}\left(\frac{\delta n \exp\left[-\left(\frac{x^2}{\delta_x^2} + \frac{z^2}{\delta_z^2}\right)\right]}{1 + \delta n \exp\left[-\left(\frac{x^2}{\delta_x^2} + \frac{z^2}{\delta_z^2}\right)\right]}\right)$$

2D Blobs/Holes

- Scaling with δn is linear for blobs but exponential for holes
  - ie a blob of 2 times background density corresponds to a hole of ½ times background density

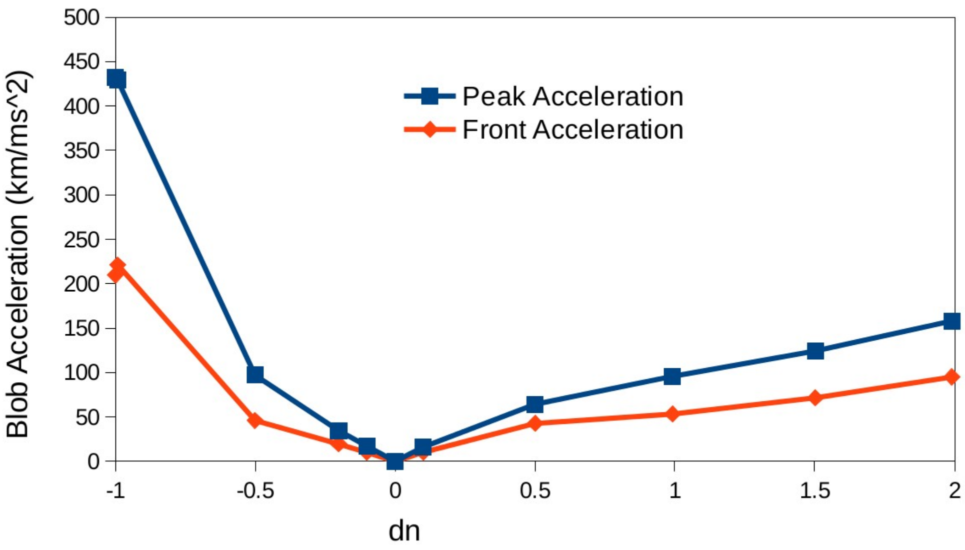


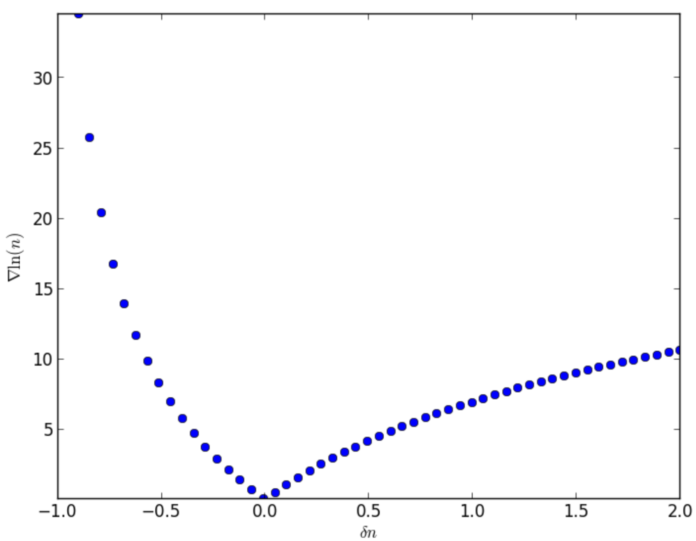
Logarithmic

2D Blobs/Holes

- Scaling with δn is linear for blobs but exponential for holes
  - ie a blob of 2 times background density corresponds to a hole of ½ times background density
- For inertially limited blobs/holes the Vorticity (or circuit) equation can be reduced to

$$a + \frac{1}{2}\nabla v^2 - c_s^2 \nabla \ln\left(n\right) = 0$$





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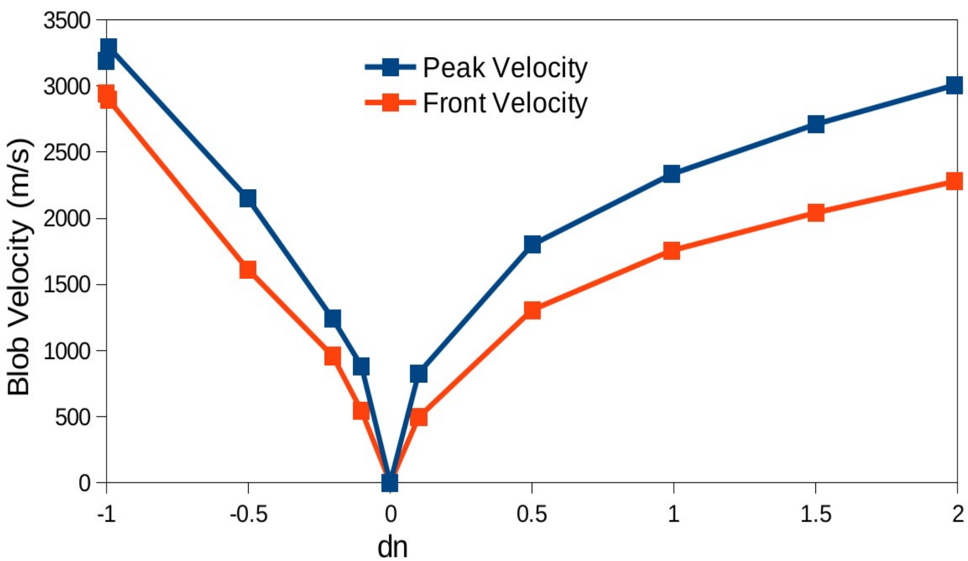
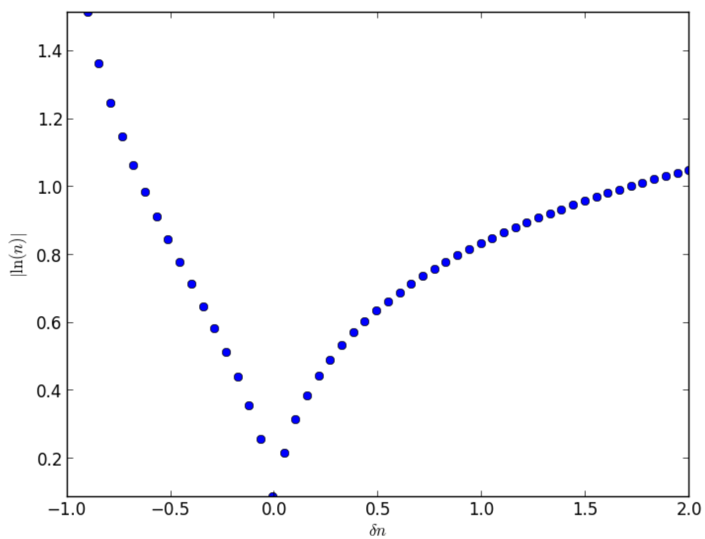
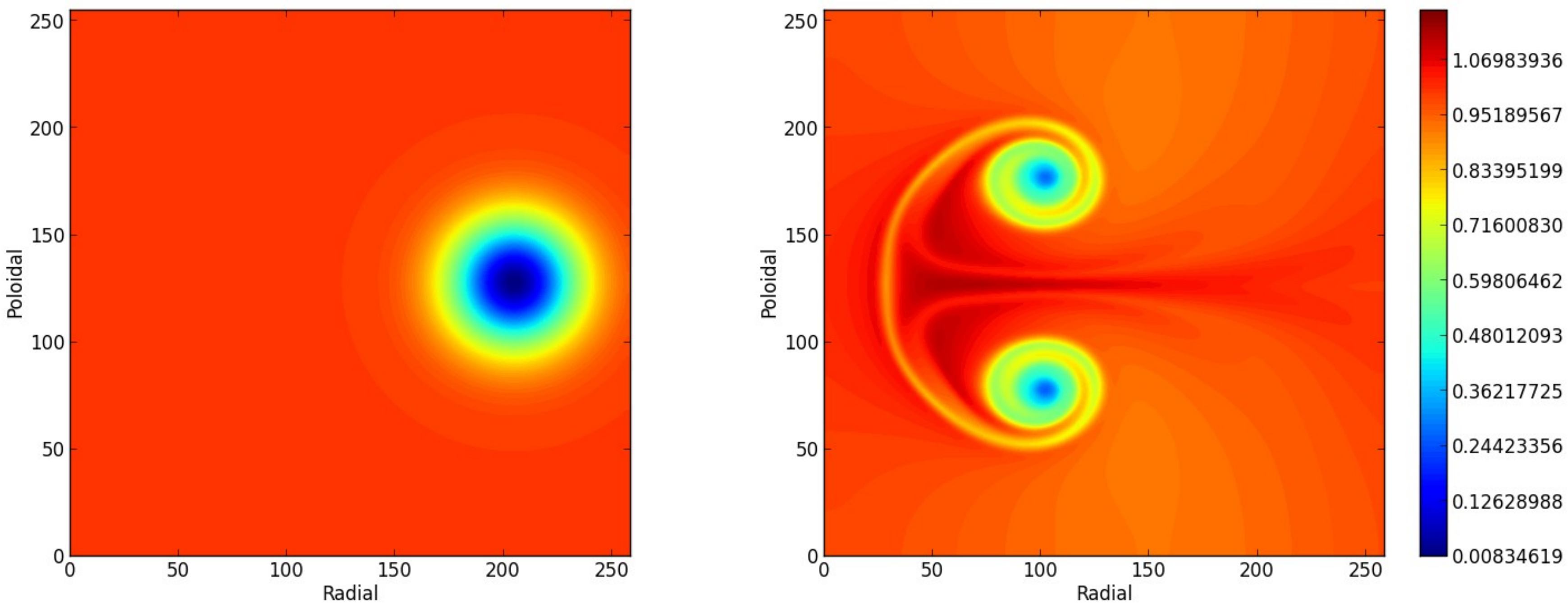




2D Blobs/Holes

- To investigate the impurity transport due to a hole, model impurities as a trace ion species
    - Requires that impurities do not affect quasineutrality
- Impurities principally transported by background and polarization flows
- Impurities become entrained in flow due to the hole motion



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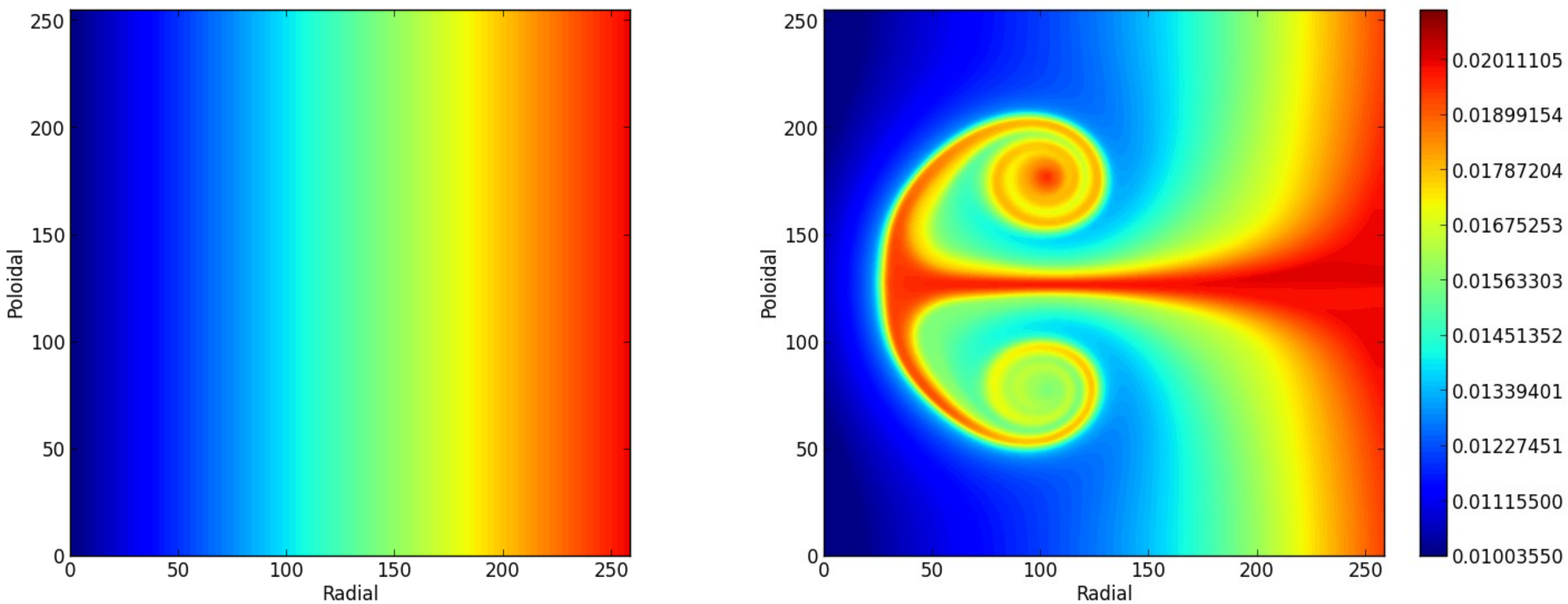

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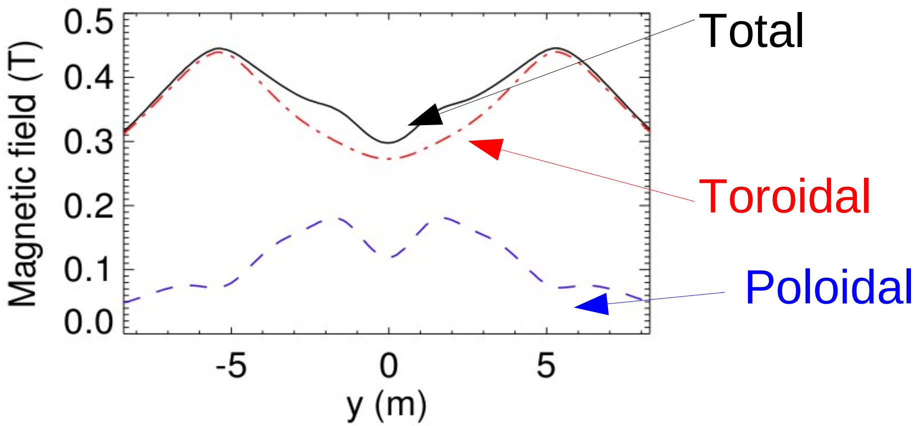
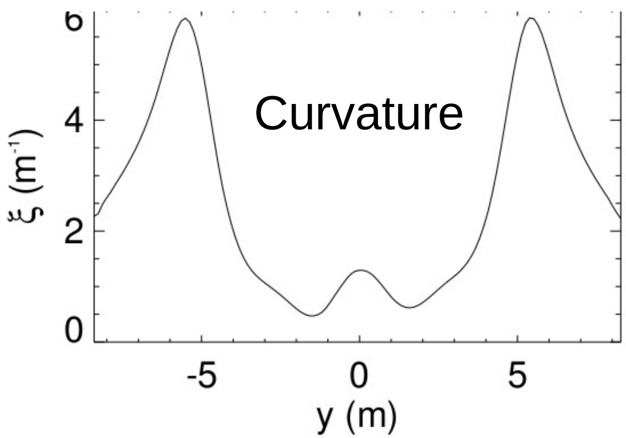
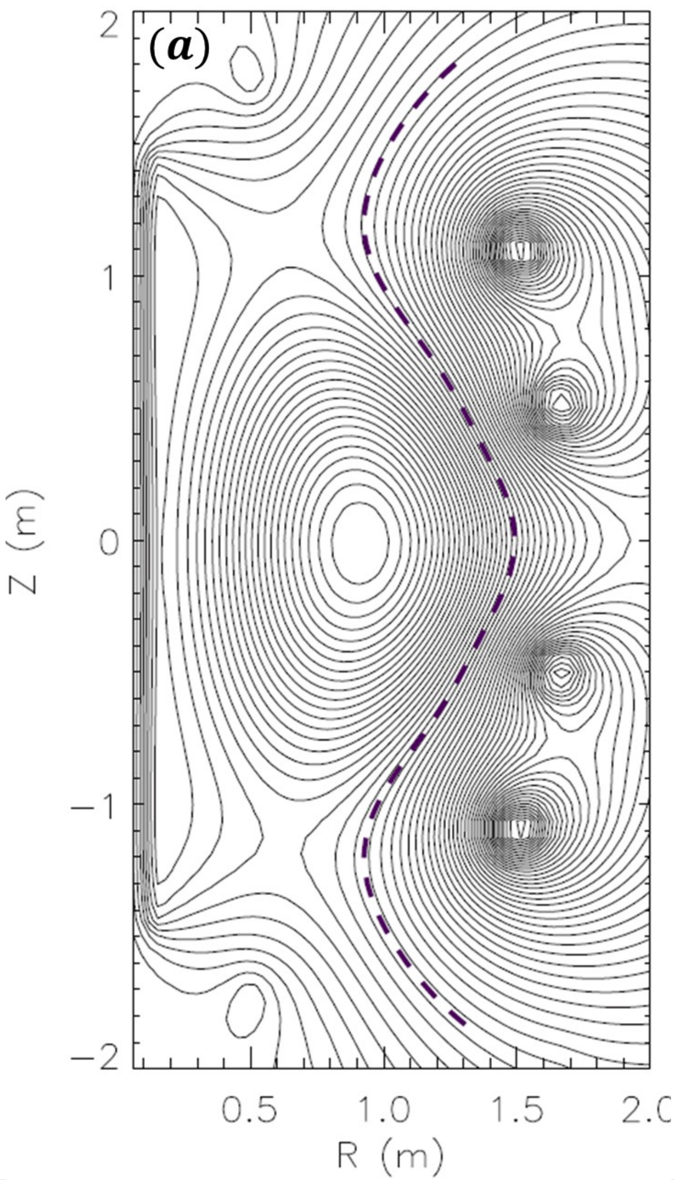
3D SOL Filaments

- 3D filament motion is strongly affected by magnetic geometry

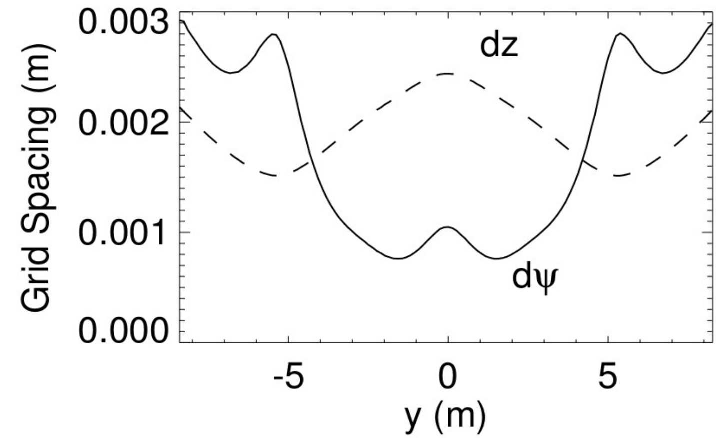


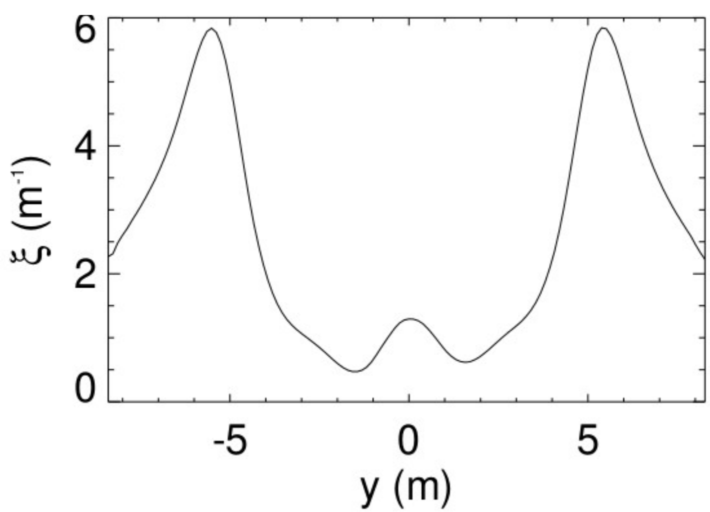


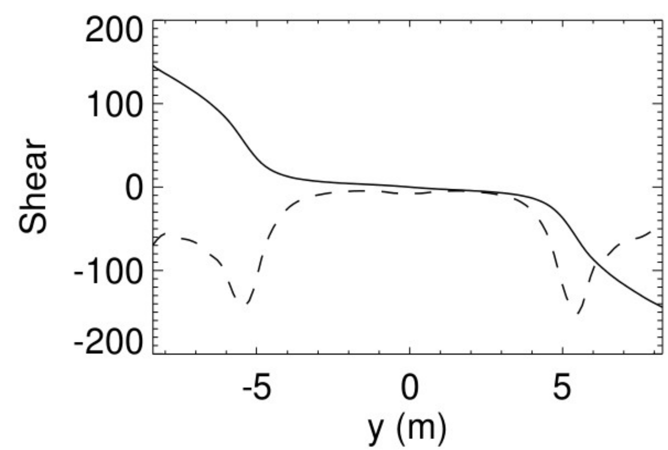


3D SOL Filaments

- 3D filament motion is strongly affected by magnetic geometry
- Curvature drives filament motion, magnetic shear and flux expansion suppress filament motion

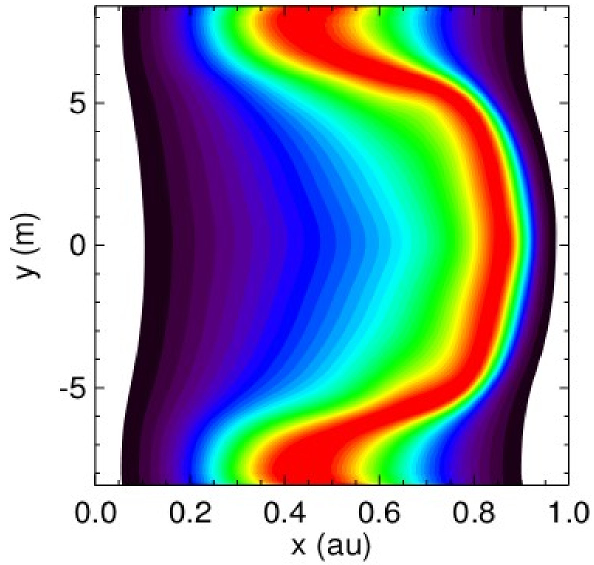






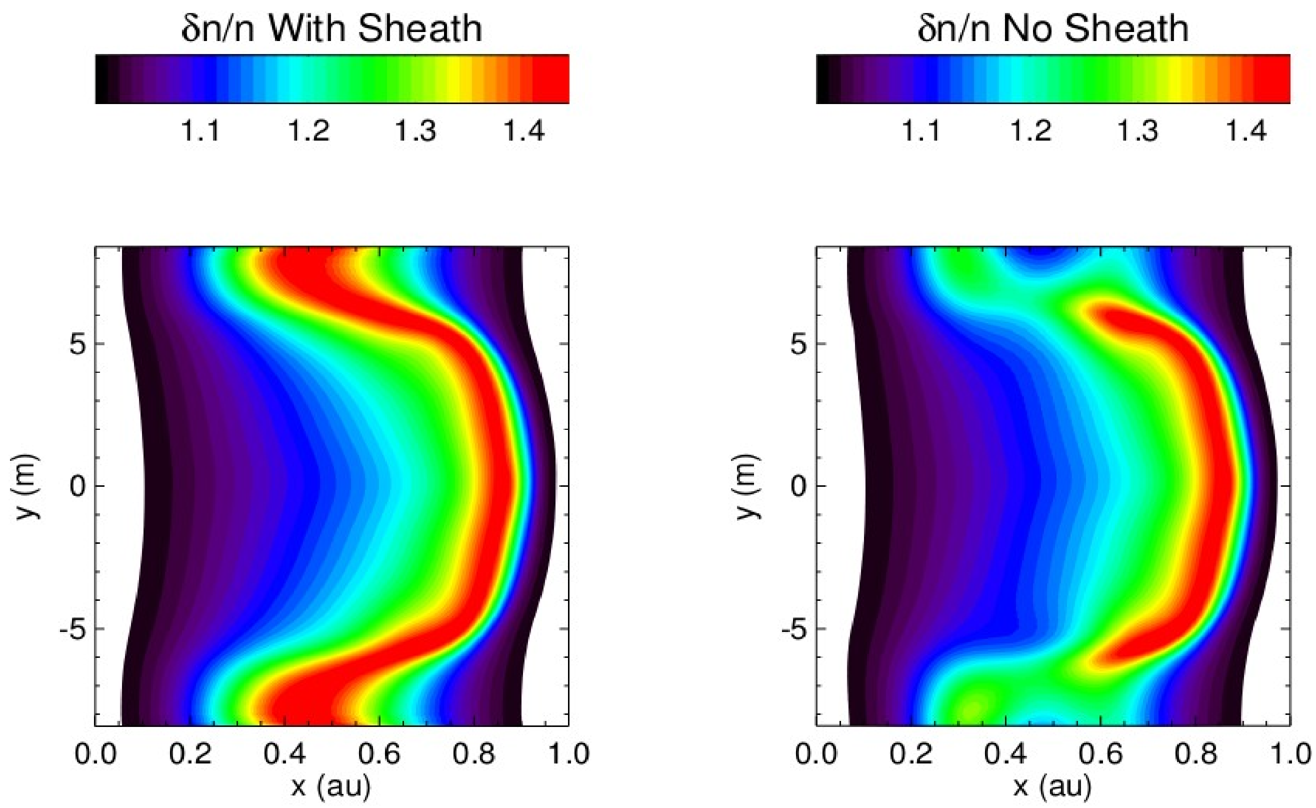
3D SOL Filaments

- MAST SOL Fluxtube geometry implemented in BOUT++
- Filaments exhibit striking 3D features



3D SOL Filaments

- MAST SOL Fluxtube geometry implemented in BOUT++
- Filaments exhibit striking 3D features
- X-points negate sheath effects on the midplane filament



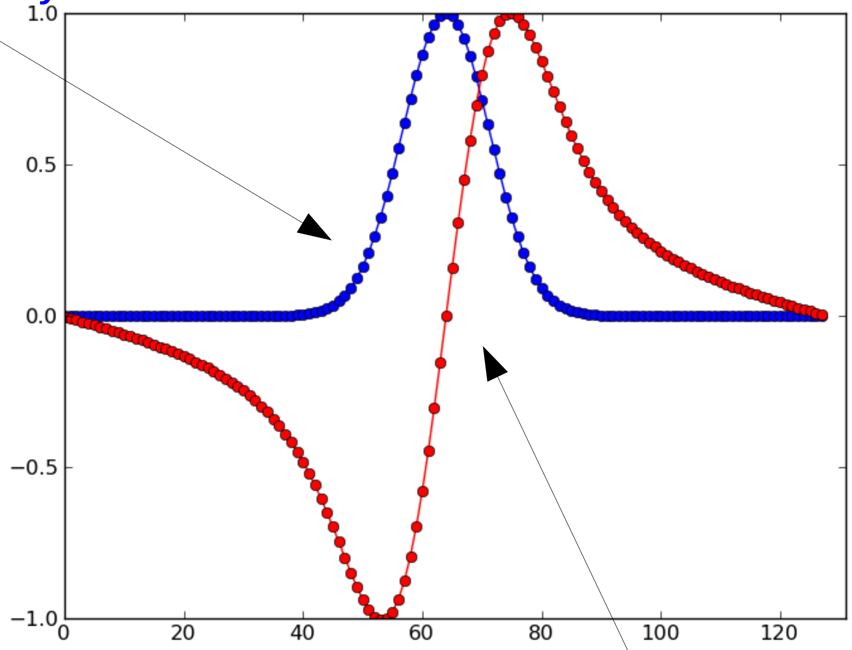
Symmetry Breaking

- Interchange motion has a well defined symmetry

- In 2D this symmetry remains unbroken

$$\rho_s^2 n \frac{d}{dt}\nabla_\perp^2\left(\phi^+ + \phi^-\right) = 0$$

Density has even parity

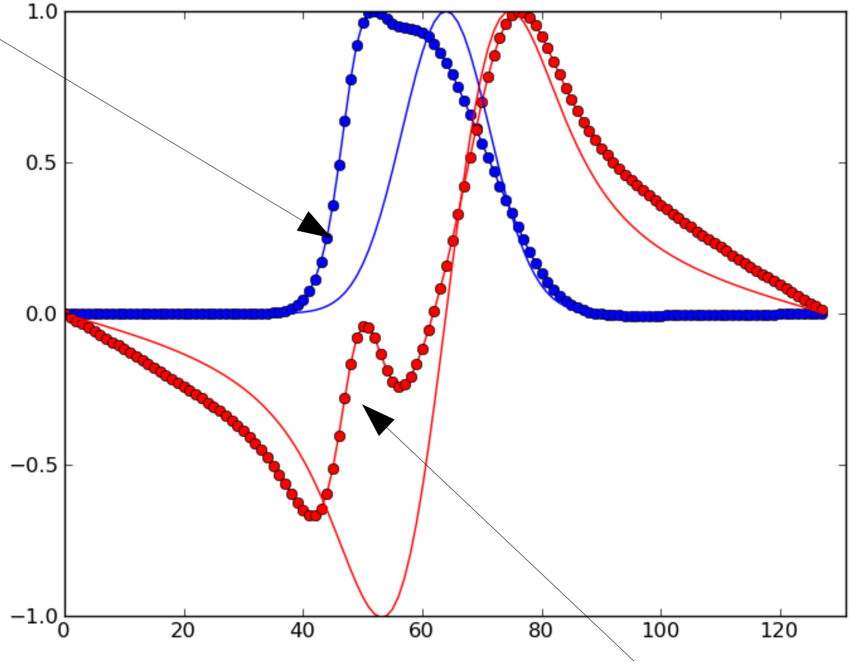


Potential has odd parity

Symmetry Breaking

- Interchange motion has a well defined symmetry

Density has mixed parity



Potential has mixed parity

- In 2D this symmetry remains unbroken

$$\rho_s^2 n \frac{d}{dt} \nabla_\perp^2 \left(\phi^+ + \phi^-\right) = 0$$

- In 3D parallel density gradients break interchange symmetry by providing another potential source

$$\frac{d}{dt} \nabla_\perp^2 \left(\phi^+ + \phi^-\right) = \frac{\sigma_{||} T_e}{e^2} \left(2\nabla_{||}^2 \ln\left(n\right) - \nabla_{||}^2 \left(\phi^+ + \phi^-\right)\right)$$

Symmetry Breaking

- Interchange motion has a well defined symmetry

Initially develops a fairly symmetric state (ie interchange mechanism initially driven)

- In 2D this symmetry remains unbroken

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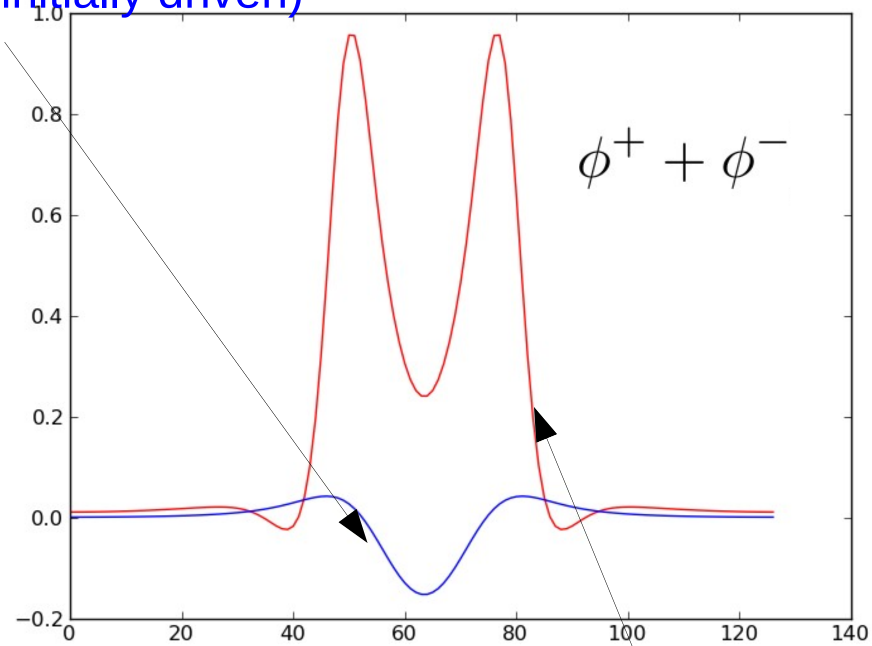

Symmetry broken as time progresses (ie Boltzmann response takes over)

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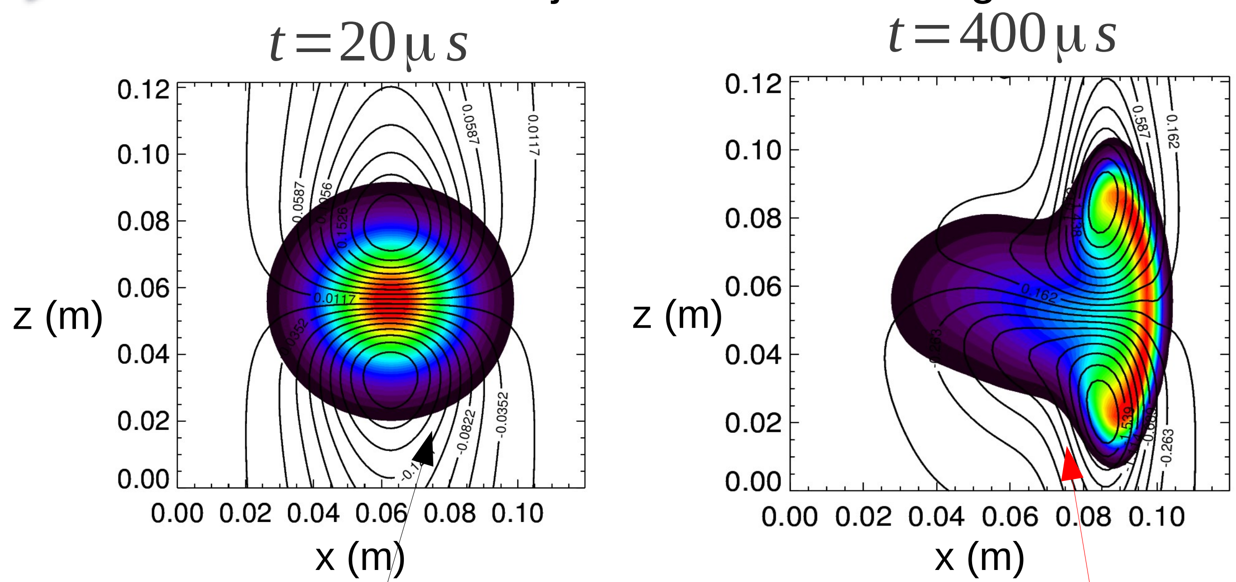
3D SOL Filaments

- Cold filaments are subject to the interchange mechanism



Color = Density

Contour = Potential

$$T_e = 1\mathrm{eV},$$

$$n_0 = 5\times 10^{18}\, m^{-3},$$

$$\frac{\delta n}{n_0} = 1$$

<u>Blob polarization</u> leading to **<u>mushrooming motion</u>** and a **<u>highly symmetric structure</u>**

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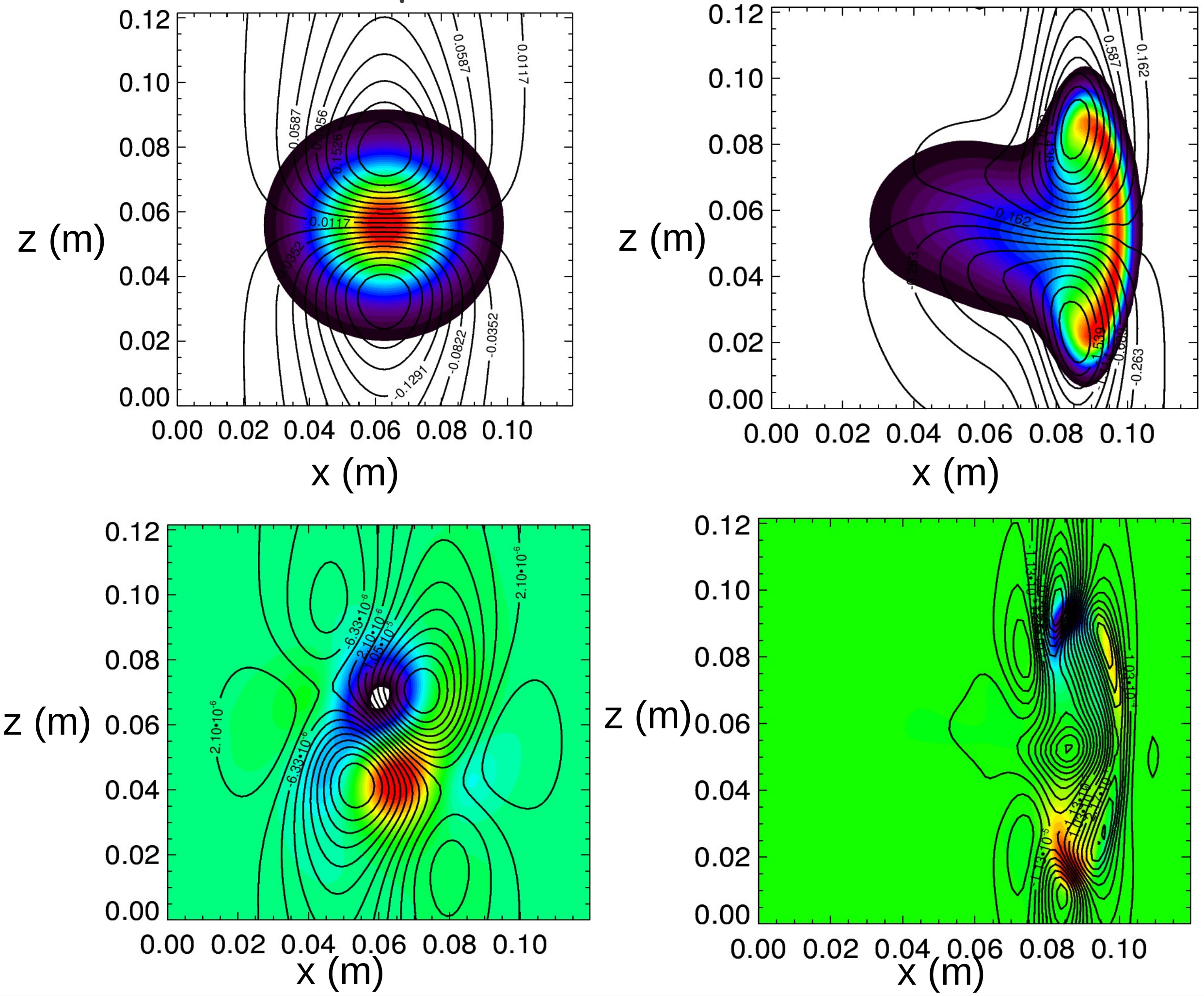
- Cold filaments are subject to the interchange mechanism

Parallel streaming time

$t = 20\,\mu s$ $\qquad$ $t = 400\,\mu s \approx 0.3\,\tau$



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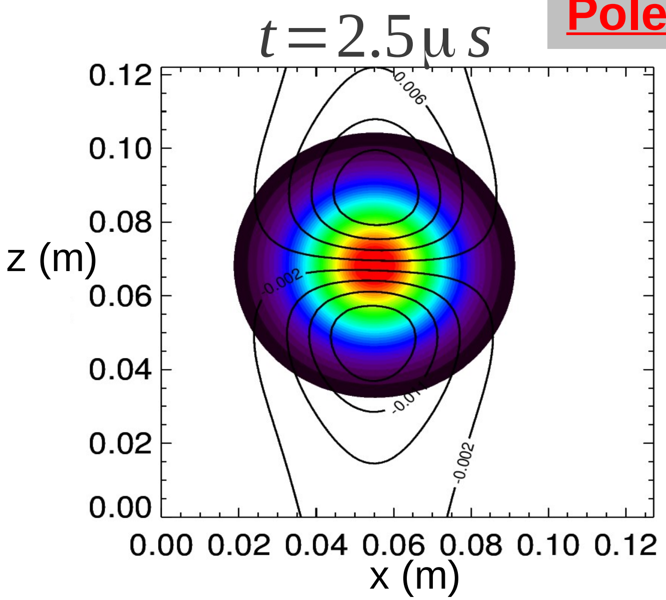
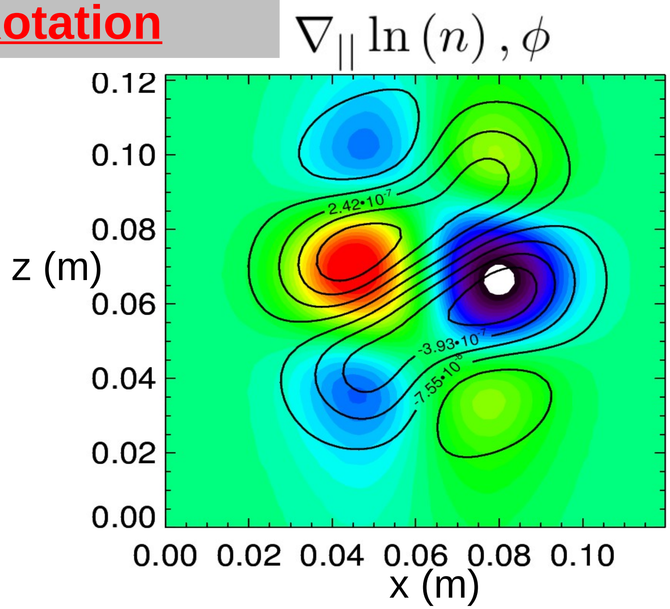
- Offset between density and potential gradients can occur due to high resistivity

3D SOL Filaments

- Hot(ter) filaments are subject to the Boltzmann response

Pole Rotation





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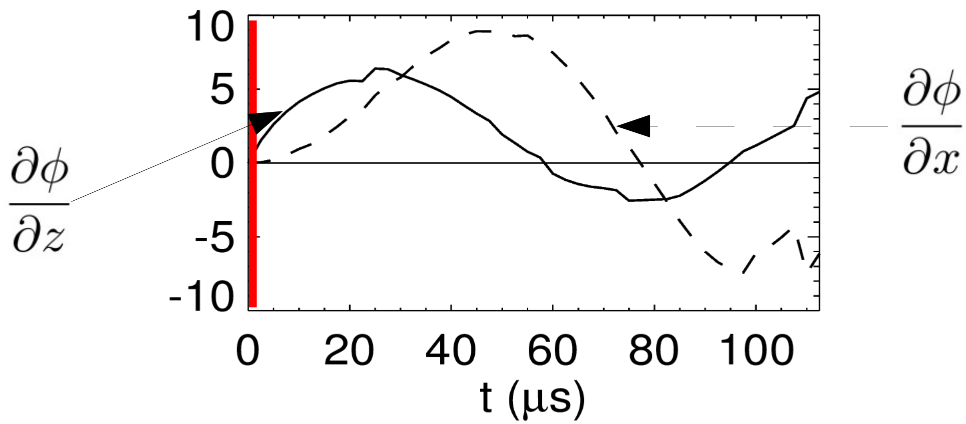

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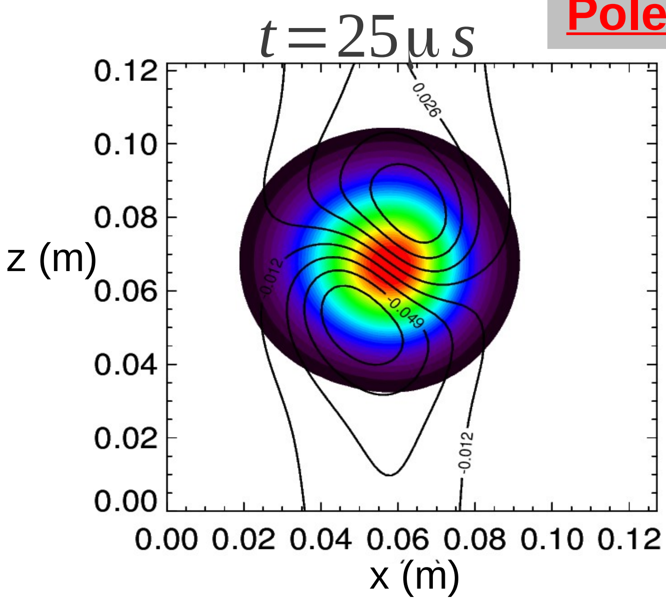

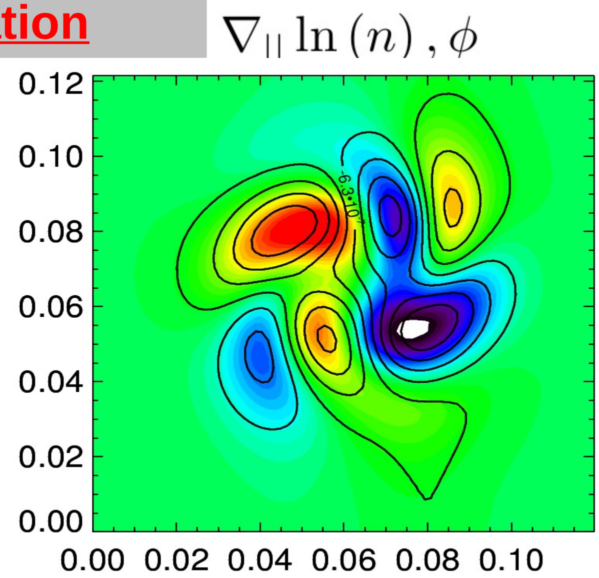

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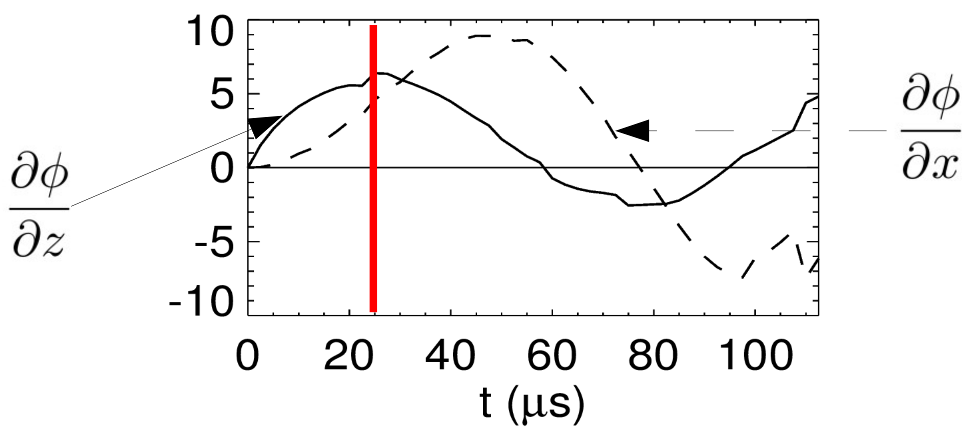

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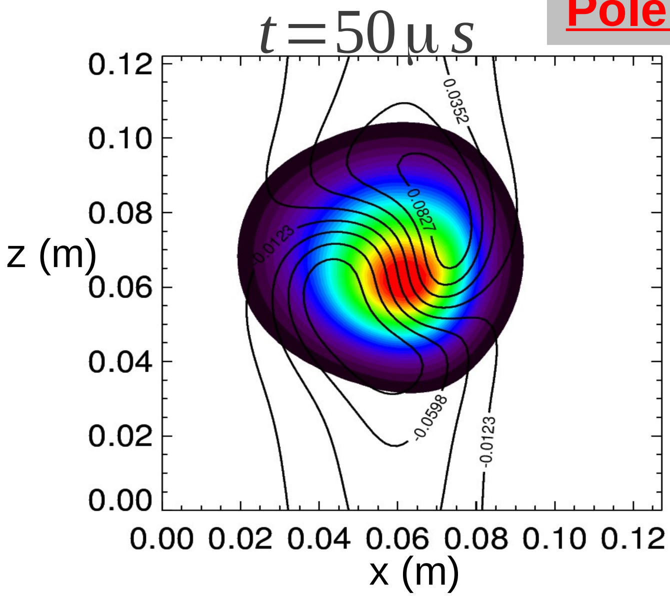

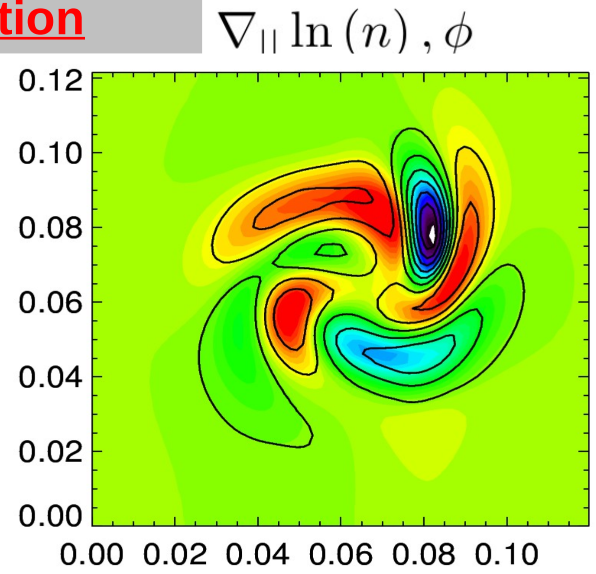

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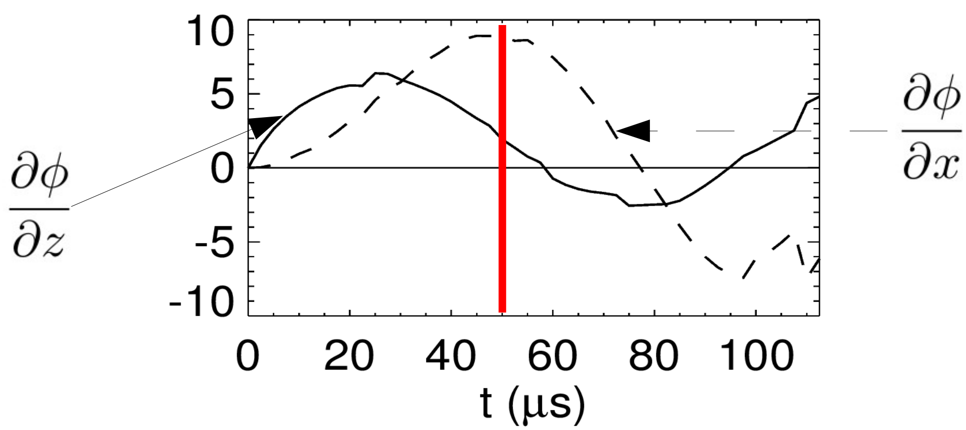

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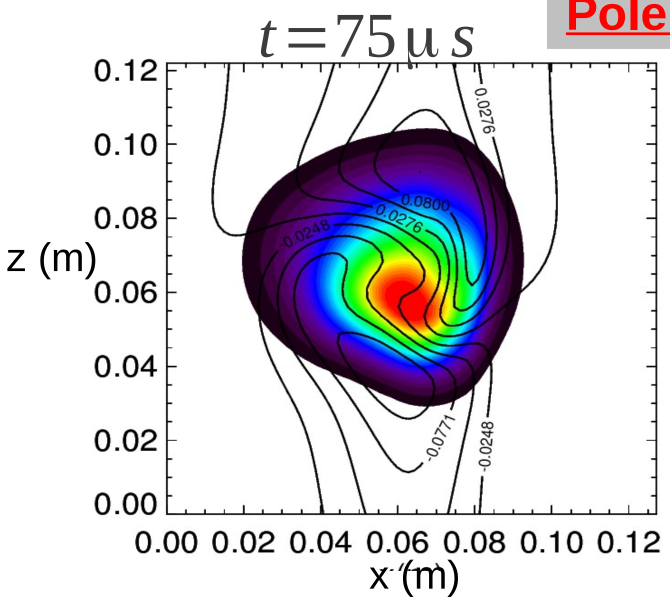

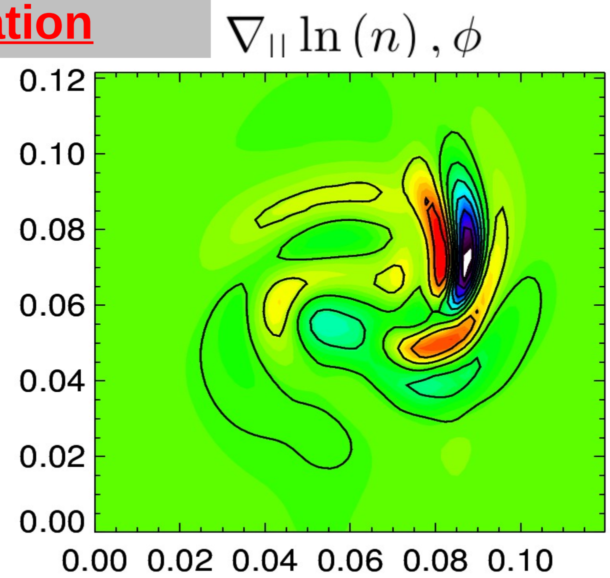

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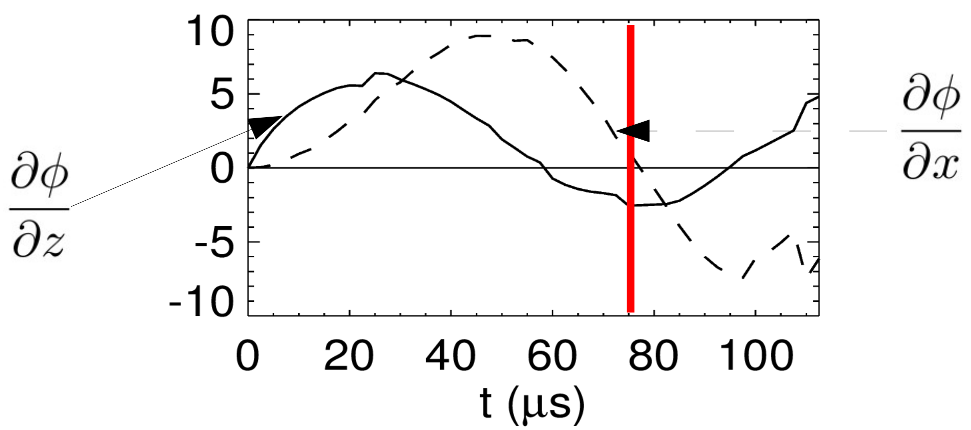


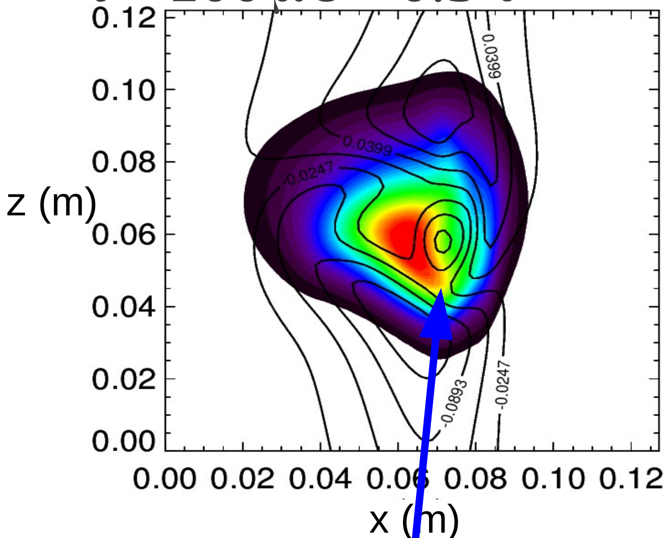
3D SOL Filaments

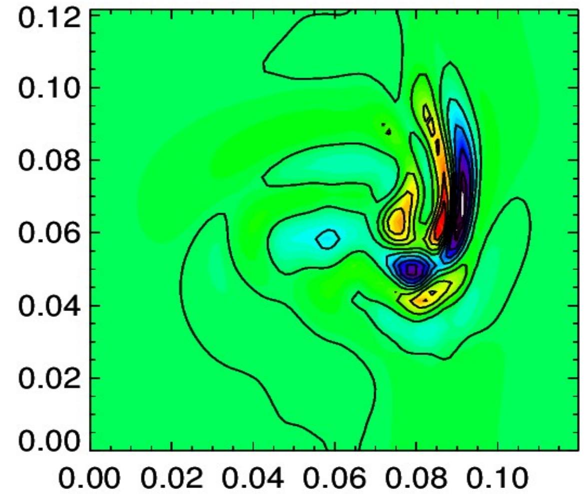
- Hot(ter) filaments are subject to the Boltzmann response

$t = 100\,\mu s \approx 0.3\,\tau$

Phase Matching

$\nabla_{||} \ln(n)\,,\, \phi$





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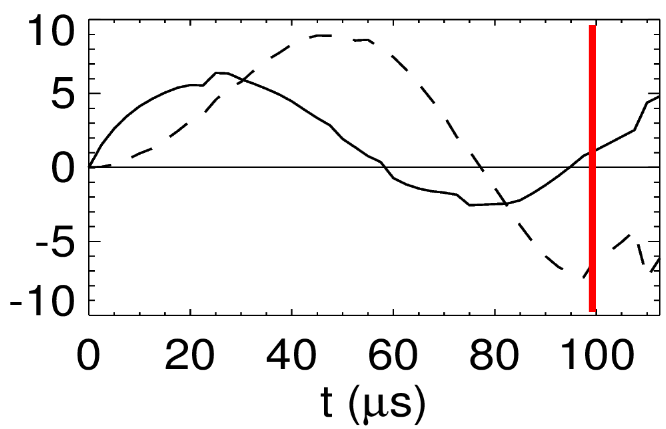
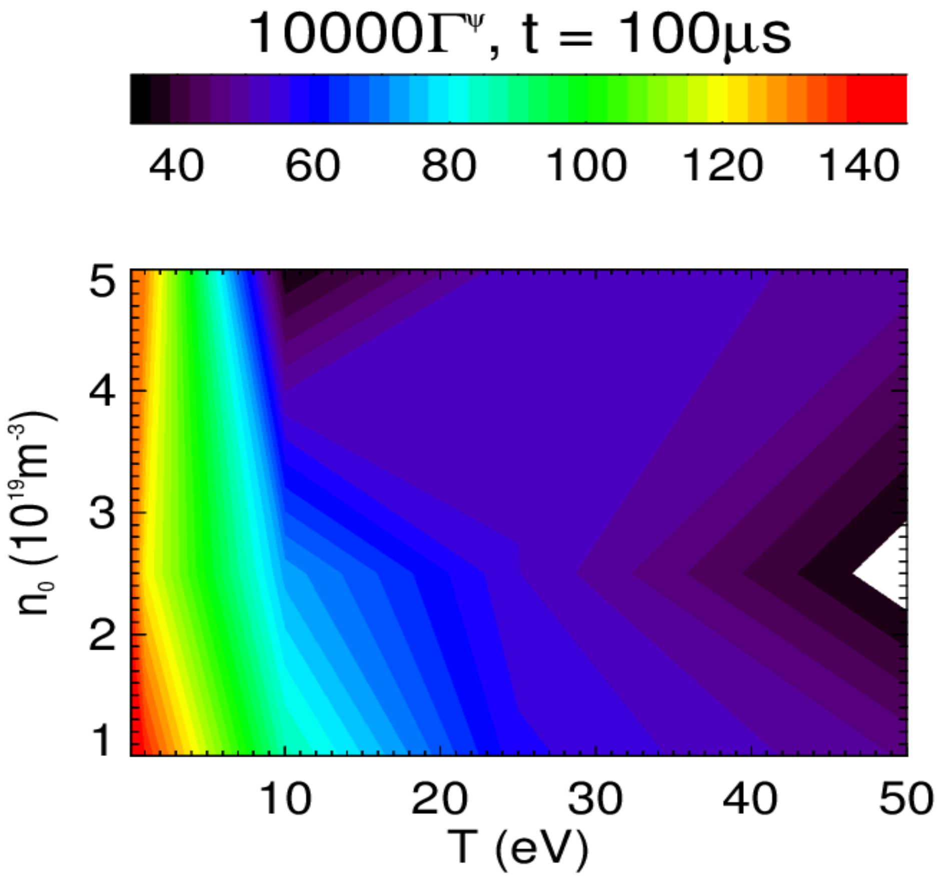
Density and potential become **highly correlated**



- Phase matching is indicative of the Boltzmann response
- Causes the filament to **spin**
- Fast parallel conduction halts charge polarization, so **spinning can become comparable to radial motion**

3D SOL Filaments

- Boltzmann response coupled to fast charge conduction drastically reduces transport radially



- **<u>BUT</u>** filaments regularly observed in the far SOL on all tokamaks
- Filament cooling near seperatrix required to facilitate interchange motion outwards?

Hot Ions

- Hot ions introduce a diamagnetic component to the flow
- It is non-advective (gyro-viscous cancellation) but can be vortical
- This modifies the vorticity such that

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Odd **Even**

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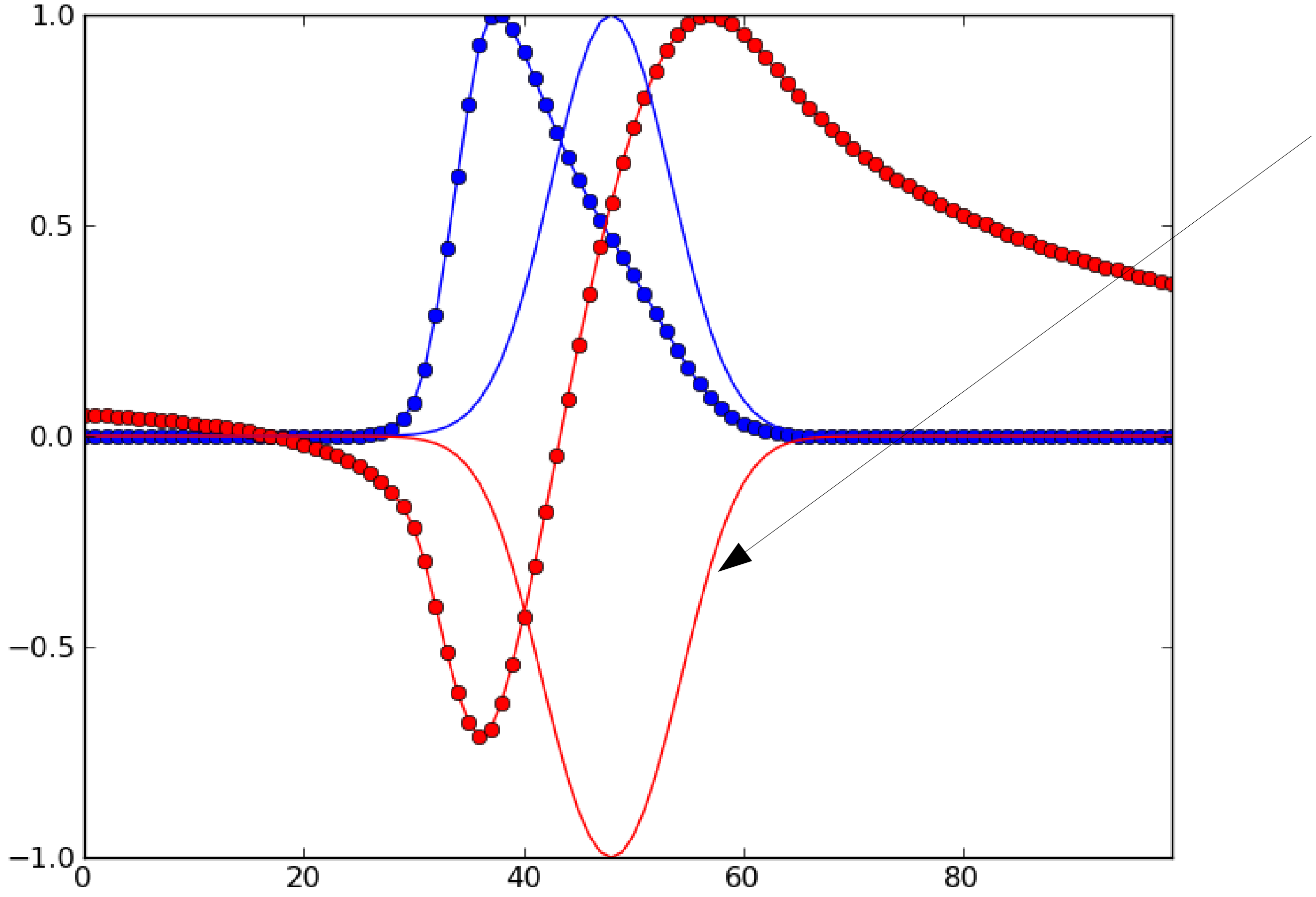
- Hot ions provide another symmetry breaking mechanism



At t=0 a potential develops to balance diamagnetic vorticity and maintain 0 net vorticity

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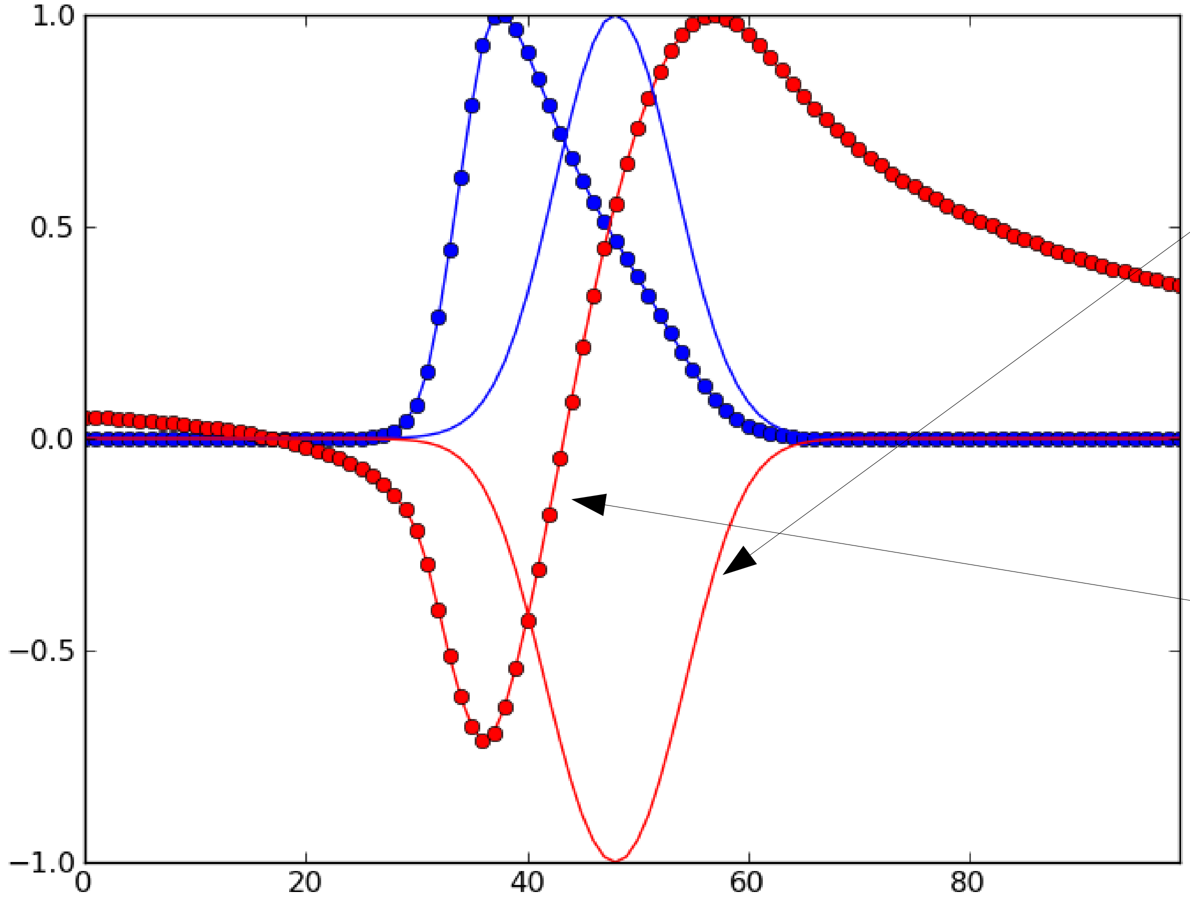

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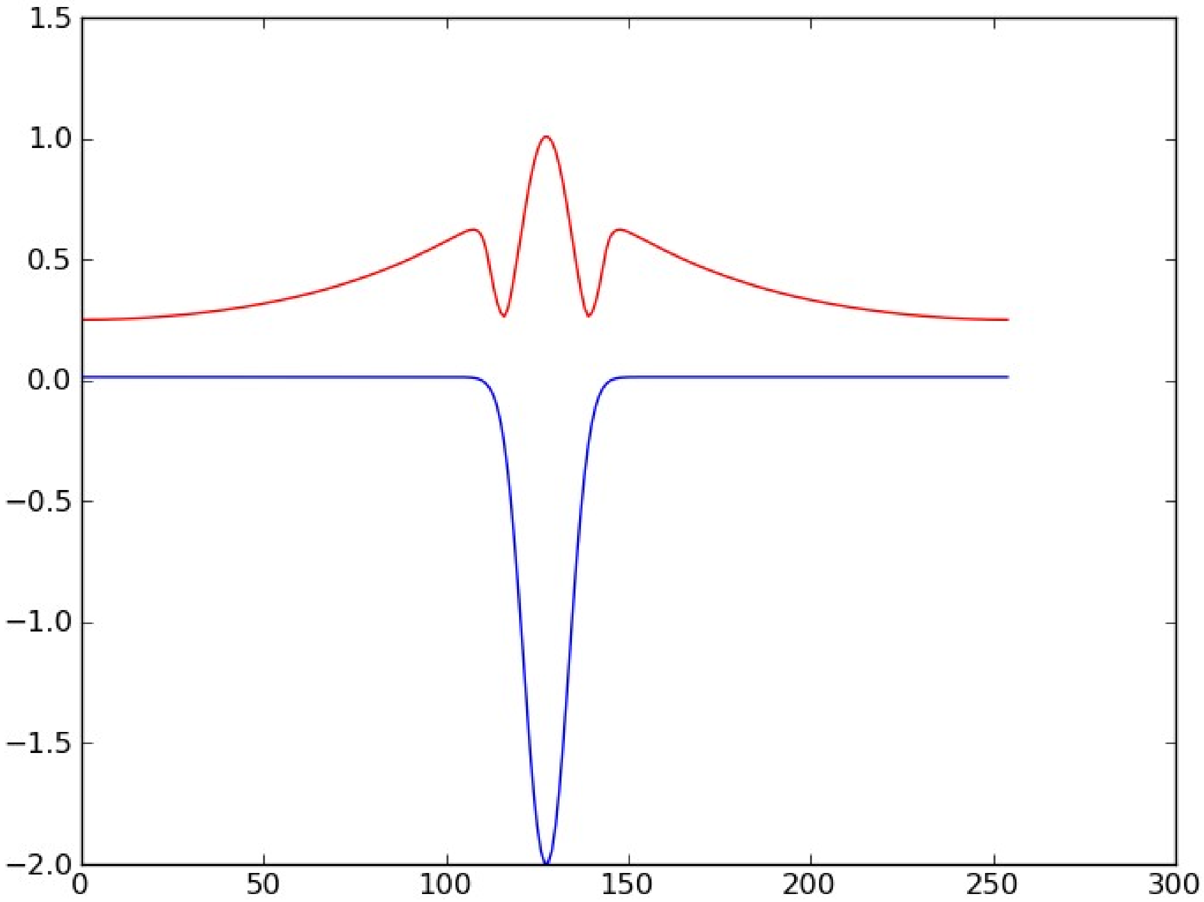

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Blob/hole velocity scales with δn asymmetrically around 0

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Walkden, Dudson and Fishpool, PPCF, **50** (2013) 105005

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Thanks for listening!

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